THE INTERRELATIONSHIPS BETWEEN QUALIFICATION, INSENSITIVE MUNITIONS AND HAZARD CLASSIFICATION TESTING OF EXPLOSIVES (HIGH EXPLOSIVES, PROPELLANTS AND PYROTECHNICS)

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Abstract

Within the U.S. and NATO communities, the terms and concepts of hazard classification, safety, Insensitive Munitions (IM) and qualification testing of all types of explosives including high explosives, propellants and pyrotechnics have caused confusion. It is the intent of this paper to clarify how the each of these terms are related and the testing that they entail. The similarities and differences between test protocols and requirements will be highlighted.

In addition to the terms and test requirements, this paper will give the reader an indication of when to conduct the testing within the framework of the acquisition cycle.

Background

As the basis from which to start the technical discussion of testing requirements, one must understand the origin of the requirements. Much of the recent efforts in the areas of hazard classification and explosives qualification trickeled down from international sources: the hazard classification guidelines of the United Nations Orange Book (Recommendations on the Transport of Dangerous Goods, Tests and Criteria) and the United State's adoption of Standardization Agreements (STANAGs) developed by two NATO Groups; AC/258 Group of Experts on the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives and AC/310 Group for the Safety and Suitability for Service of Munitions and Explosives. In the body of the paper, reference will be made to the appropriate NATO STANAGs of those two Groups.

The requirements for hazard classification, qualification and IM testing deal with substances and articles which in some documentation are referred to as explosives and munitions. For consistency in this paper, the terms explosives and munitions will be used unless a distinct need is indicated to do otherwise.

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For clarity, the definitions of "Qualified" and "Final (or Type) Qualified" explosives are stated below. These definitions have been excerpted from NATO STANAG 4170.

Qualified Explosive: An explosive is qualified when it has been assessed by the National Authority and adjudged to possess properties which make it safe and suitable for consideration for use in a particular role (e.g. as a main charge filling, a booster, propellant, gun propellant, illuminant pyrotechnic, etc.). This is an intermediate stage leading to:

Final (or Type) Qualification: Final (or Type) Qualification relates to the use of the explosive in a specific application or weapon system. Final Qualification is given when the explosive has been assessed as part of the design of the specific weapon, and shown to be safe and suitable for military operations or training use in that role.

Hazard Classification

In general, Hazard Classification of explosives and munitions is required throughout NATO and UN Nations for purposes of providing safety in transportation and storage. Data are developed by agreed test protocols which are then assessed to agreed criteria. The items are categorized as:

1.1 (Mass Detonating)
1.2 (Non Mass Detonating/Fragment Producing)
1.3 (Mass Fire)
1.4 (Moderate Fire)
1.5 (Very Insensitive Explosive Substance with a Mass Explosion Hazard)
1.6 (Extremely Insensitive Detonating Substances, and Articles, Extremely Insensitive)

It is the latter two categories which often causes confusion with personnel involved in Insensitive Munitions (IM) and Insensitive High Explosives (IHE) efforts.

Hazard Classification is governed by national, United Nations and NATO documentation. In the United States, the document is titled "Department of Defense Explosives Hazard Classification Procedures" and is used by all services (TB 700-2, NAVSEAINST 8020.8 and TO 11A-1-47) and the Department of Defense Explosives Safety Board (DDESB). Internationally Hazard Classification is governed by the UN Orange Book "Recommendations on the Transport of Dangerous Goods, Tests and Criteria." The test

series of the UN Orange Book are referenced in STANAG 4123 (AC/258) "Methods to Determine and Classify the Hazards of Ammunition."

Hazard classification testing is performed at the end of the development process on the final munition design to be released to production. Testing is done in the transportation or storage configuration.

Insensitive Munitions

Insensitive Munitions efforts originated in the United States with the US Navy as the principal proponent. The US Navy interest was primarily focused on improving the survivability of ships when exposed to munitions reactions initiated by combat induced environments. National safety programs historically assessed a munitions vulnerability to environmental forces produced during the normal logistic cycle and by reasonably forecasted accident scenarios.

In 1987, the three U.S. Services signed a Joint Memorandum of Agreement to make all services munitions insensitive using the least sensitive explosive materials which will meet operational requirements. Mechanical means may be utilized to augment the insenstiive material when needed to reduce the reaction violence or protect the munition from the initiation source. The emphasis of the each Services IM Program varies due to mission requirements. While the Navy emphasis is on ship survivability, the Army is concentrating on armored vehicles such as the Bradley Fighting Vehicle and the Air Force on air base survivability. Each service under the multi-service agreement has formal implementing documentation. A multi-service test document, MIL-STD-2105 Revision B, is currently in staffing. This document identifies basic and optional safety and IM test protocols. Attempts have been made to standardize these tests with NATO and UN Hazard Classification test protocols. The document is also written so that the individual weapon program manager can tailor a hazard assessment test program to meet the life cycle environmental exposure of the particular munition.

Several NATO nations and indeed NATO, within the AC/310 Group, are developing individual Insensitive Munitions programs. National programs will no doubt vary in goals and test requirements due to the various national military defense postures and needs. The NATO program needs to address some core considerations and tests with options to suit individual national and service needs.

Internationally, NATO AC/310 is addressing IM in draft STANAG 4439 stating the overall policy and program; and in test STANAGs on classes of munitions (air launched, surface launched, etc.) and specific hazard tests (Bullet Impact, Fast Cook-off, etc.). Again, attempts are being made to standardize when possible.

The Development to Production Process

Testing for insensitive munitions and safety is performed on weapon design and explosive formulation iterations and is intended to verify the substance or article meets certain specified requirements. Design is affected and design changes are retested to verify the ability to meet requirements. Final Qualification and Insensitive Munitions criteria are only fulfilled when the testing is conducted on the most vulnerable configuration of the final design as determined by a hazard analysis.

Before discussing individual test requirements for explosives and munitions, let us discuss the normal procedure of munitions design efforts from development through production with a look at what happens at various milestones and where Qualification, Insensitive Munitions and Hazard Classification considerations enter the process. (See Figure 1)

Within the development process, the first step is Basic Research and Development. Generally, at this point in time, the emphasis is on synthesizing new explosive molecules such as the relatively recent development of CL-20. These are the building blocks of future formulations. Certainly in characterizing these new materials, some safety data are generated to rule out materials of extreme sensitivity, toxicity, etc.

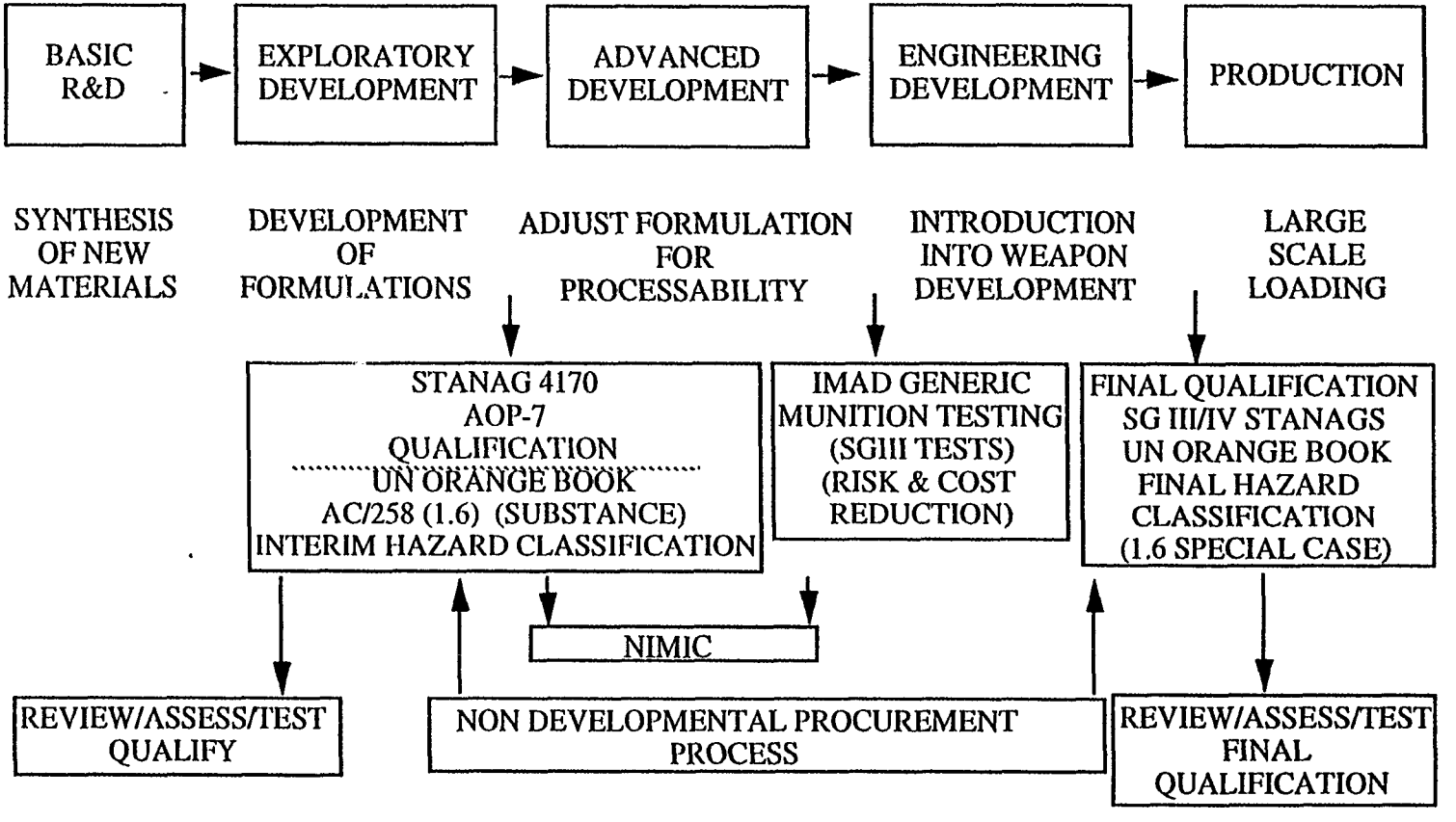
Moving on to the Exploratory Development phase, new materials or different combinations of older materials are used in the development of new formulations. In this process many undesirable features of the basic material (e.g. sensitivity) can be rendered acceptable by proper formulation efforts. It is the formulation which will be further improved for actual use in a munition. Again, basic safety test data on the materials will be collected.

When the formulation has matured, through experimentation, it may be considered ready for Advanced Development where the properties of the formulation are adjusted for processability. In some instances to achieve optimum viscosity, cure times, or other parameters, sufficient changes in the formulation may need to be made.

It is at the completion of this phase the Qualification tests of STANAG 4170 are conducted. Testing of certain critical sensitivity characteristics will have been repeated perhaps several times until the optimized formulation for safety, insensitive munitions and performance is reached. Should a 1.6 EIDS Hazard Classification be sought, the test series 7 of the UN Orange Book as referenced in STANAG 4123 (AC/258) will be conducted.

Within the United States, many of our new formulations, especially high explosives and to some degree propellants, are tested in generic hardware, such as within the U.S. Navy

DEVELOPMENT TO PRODUCTION PROCESS



Insensitive Munitions Advanced Development (IMAD) Program, just prior to entering Engineering Development.

These generic units undergo safety, vulnerability and performance tests. The generic units have been designed to simulate weapon configurations such as penetrator and fragmenting warheads. The results of this testing provides weapon designers with data they can use in their designs reducing the risk, cost and time to deployment of the actual system.

With the known safety and performance characteristics from the qualification test series on the explosive formulation and the generic warhead data, an informed selection can be made to introduce the material into a munitions development program. As the marriage of the material and munition progresses, the safety and IM tests of MIL-STD-2105 and the NATO AC/310 Subgroup IV STANAGs are conducted to verify that the munition design meets set requirements. The tests are conducted on the final production design. In instances where design iterations are required to meet requirements, retesting of the redesign is necessary.

Upon satisfactory completion of Engineering Development, the explosives and munitions are submitted for Approval for Production. All of the testing which was conducted during Engineering Development is documented and a data package forwarded to the appropriate Service authority requesting release of the explosive, as used in the munition, for production and operational use. Approval constitutes Final (or Type) Qualification.

Final Hazard Classification requests are also submitted after having completed testing in accordance with National documents, STANAG 4123 and the U.N. Orange Book (Transportation).

Explosive Materials Testing

Figure 2 lists a variety of explosive tests, both mandatory and optional for Qualification, Hazard Classification and EIDS certification. The test requirements of STANAG 4170 are referenced. The United States has ratified STANAG 4170 and is in the process of circulating a draft of MIL-STD-1751A to serve as the tri-Service, U.S. implementing document for STANAG 4170. When the military standard is adopted, the STANAG 4170 test requirements will be the U.S. standard. The requirements of STANAG 4123 and the U.N. Orange Book for Hazard Classifications 1.1 through 1.5 as well as the special category for 1.6 EIDS are also detailed in Figure 2.

FIGURE 2 EXPLOSIVES QUALIFICATION REQUIREMENTS	QUALIFICATION STANAG 4170	HAZARD CLASSIFCATION 1.6 (EIDS) STANAG 4123/UN ORANGE BOOK	HAZARD CLASSIFCATION 1.1 - 1.5 STANAG 4123/UN ORANGE BOOK
Impact Sensitivity	Mandatory	Test Series 3	Test Series 3
Friction Sensitivity	Mandatory	Test Series 3	Test Series 3
Electrostatic Sensitivity	Mandatory		
Gap Sensitivity	Mandatory	Test Series 7	Test Series 1 & 2
Cap Sensitivity	Mandatory	Test Series 7	Test Series 5
Critical Diameter	Mandatory		
Self Heating (DTA/DSC)	Mandatory		
Thermal Stability	Mandatory	Test Series 3	Test Series 3
Ignition & Unconfined Burning	Mandatory		Test Series 1 & 2
Toxicity Evaluation	Mandatory		
Detonation Velocity	Mandatory		
Min. Pressure Vapor Phase Transition	Mandatory *		
Flash Point	Mandatory *		*
Detonability	Mandatory *		
Small Scale Cook Off	Optional		
Growth	Optional		
Exudation	Optional		
Hot Wire Ignition	Optional		
Susan Impact	Optional	Test Series 7	
Small Scale Burn		Test Series 3	Test Series 3
Friability		Test Series 7 **	
Bullet Impact (Single)		Test Series 7	
External Fire		Test Series 7	
Slow Cook Off		Test Series 7	
Single Package Test			Test Series 6 ***
Propagation Stack (Packages)			Test Series 6 ***
External Fire (Packages)			Test Series 6 ***

Notice that for explosives alone, not in packaging, with the exception of the small scale burn requirement, all tests for Hazard Classification 1.1 to 1.5 are contained within the requirements for explosives Qualification.

EIDS Hazard Classification requirements are in addition to explosives Qualification requirements. To satisfy EIDS requirements, the explosives must pass small scale vulnerability tests in addition to basic safety and performance tests. Consideration should be given, anytime an explosive is proposed for EIDS certification, to use tests for the common data needs which will preclude redundant testing.

Munitions Testing

The requirements for Final (or Type) Qualification, Hazard Classification, Safety and Insensitive Munitions testing also overlap in several areas. But at the same time, there are subtle differences between the test parameters for the same types of tests, and the pass/fail criteria are different in many instances. Most relate back to the differences between the purposes of the tests; Hazard Classification for transportation/storage configurations and Insensitive Munitions (Final Qualification) testing for combat and logistics scenarios and configurations.

Figure 3 defines the Final (or Type) Qualification test requirements from STANAG 4170 as ratified by the United States. These tests also serve as the baseline Insensitive Munitions tests. Tests are generally performed on the most vulnerable life cycle configuration of the item. This testing also provides data required for Safety and Insensitive Munitions compliance verification. There are seven (7) tests listed as core tests. These tests must be performed unless rationale is provided to the proper authority that the test environment does not represent a plausible life cycle exposure. Prior to performing these tests, the explosive must be Qualified.

The figure also contains the test requirements for Final Hazard Classification for munitions and the special Hazard Classification 1.6. The Hazard Classification test series are conducted on packaged munitions. To make the tests interchangeable, Final Qualification tests would need to be done on the packaged configuration. In some instances, this may be the most vulnerable munitions configuration based on life cycle analysis.

The external fire test may be conducted with jet fuel as required by the Final Qualification test specification, MIL-STD-2105A. The Sympathetic Detonation test may also be considered acceptable in lieu of the Propagation Stack Test. Further, if in these two tests, a single item exhibits a "mild" reaction, multiple unit tests may not be required.

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FIGURE 3
U.S. MUNITION (ARTICLE) TESTS

TEST	FINAL TYPE QUALIFICATION STANAG 4170	HAZARD CLASSIFICATION STANAG 4123/UN ORANGE BOOK	
		1.6****	1.1 - 1.4***
FAST COOK OFF (FUEL FIRE)	MANDATORY **		
EXTERNAL FIRE		MANDATORY	MANDATORY *
SLOW COOK OFF*****	MANDATORY	MANDATORY	
BULLET IMPACT (MULTIPLE)	MANDATORY	MANDATORY	
SINGLE PACKAGE TEST			MANDATORY
SYMPATHETIC DETONATION	MANDATORY **		
PROPAGATION STACK TEST		MANDATORY	MANDATORY *
FRAGMENT IMPACT	MANDATORY		
SHAPED CHARGE JET*****	OPTIONAL (HAZARD ANALYSIS)		
SHAPED CHARGE SPALL*****	OPTIONAL (HAZARD ANALYSIS)		
REQUISITE FOR SUBSTANCES	QUALIFIED PER STANAG 4170	EIDS PER STANAG 4123	

* Mild reaction in single item tests may negate need for multiple unit test.

** May be acceptable as Test Series 7 test if conducted in transport configuration.

*** Test Series 6

**** Test Series 7

***** Required unless determined not to be a credible threat by analysis.

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Figure 4 shows the passing criteria for Final Qualification/ Insensitive Munitions and Hazard Classification 1.6. With the exception of the Bullet Impact and Fuel Fire (Bonfire) tests, the passing criteria are essentially the same. For Bullet Impact, the Insensitive Munitions acceptance criteria are more stringent, "burning only", than the EIDS criteria of "reaction less than detonation." For the Fuel Fire, the Insensitive Munitions acceptance criteria is less stringent "burning only" than the EIDS Article criteria of no "Division 1.1, 1.2 or 1.3 reaction."

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FIGURE 4
U.S. CRITERIA
MUNITIONS (ARTICLES)

	FINAL (TYPE) QUALIFICATION INSENSITIVE MUNITIONS	HAZARD CLASSIFICATION 1.6
BULLET IMPACT	BURNING MAXIMUM	
SLOW COOK OFF	BURNING MAXIMUM	
* FAST COOK OFF	BURNING MAXIMUM	LESS THAN DETONATION
EXTERNAL FIRE		BURNING MAXIMUM
FRAGMENT IMPACT	BURNING MAXIMUM	ANY RESPONSE THAT DOES NOT CLASSIFY ITEM AS 1.1, 1.2, 1.3
**SYMPATHETIC DETONATION	NO DETONATION PROPAGATION	
PROPAGATION TEST		NO DETONATION PROPAGATION
SHAPED CHARGE JET	NO DETONATION PROPAGATION	
SHAPED CHARGE JET SPALL	NO PERSISTENT BURNING	

* MAY BE ACCEPTABLE AS EQUIVALENT TO EXTERNAL FIRE TESTS FOR HAZARD CLASSIFICATION 1.6 IF PERFORMED IN PACKAGED CONFIGURATION

** MAY BE ACCEPTABLE AS EQUIVALENT TO PROPAGATION TEST FOR HAZARD CLASSIFICATION 1.6 IF PERFORMEND IN PACKAGED CONFIGURATION

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Conclusions which can be drawn from this chart in combination with the previous one:

(1) Acceptance as a 1.6 Article does not necessarily mean that the munition is an Insensitive Munition.

(2) An Insensitive Munitions is not a 1.6 Article unless it is filled with an EIDS.

(3) An Insensitive Munitions Article containing a 1.1 Mass Detonating substance could be classified as a 1.2 Article (Fragmentation Hazard). Smaller items could be classified as 1.4.

Recommendations

The following recommendations are offered:

If the Hazard Classification 1.6 is desired, because of the requirements for the use of an EIDS and the stringent test acceptance criteria, this decision should be made early in the design effort to have the most impact on weapon design.

With regard to testing of substances, the test requirements of STANAG 4170 and STANAG 4123 Test Series 3 and 7 need to be standardized as much as possible.

The same direction should be pursued in the standardization of STANAG 4123 Test Series 7 and the United States Insensitive Munitions tests.

The benefits of achieving standardization include:

The redundant tests are eliminated.

The risk to the weapon developer is reduced.

Less testing translates into greater affordability.

Development costs are minimized.

More consistent testing will develop a stable data base from which to base STANAG requirements.

Standardization among Nations will increase the interoperability of weapons, especially important in the reduced budget environment.

And, the overall safety of weapons and their suitability for service will be increased to the benefit of all.